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Indirect search of exotic mesons: $B \to J/\psi + Anything$

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Summary. — We reconsider the discrepancy between theory and data in the momentum distribution of slow J/ψ in B decays. Besides an update of the standard color singlet and color octet QCD components, we include the contribution from XYZ exotic mesons, and show that the residual discrepancy could be accommodated considering new XYZ mesons still unobserved.

PACS 14.40.Rt – Exotic mesons.
PACS 13.85.Ni – Inclusive production with identified hadrons.
PACS 13.25.Hw – Decays of bottom mesons.

In the last ten years the search for excited charmonium and bottomonium states has revealed the existence of a number of resonances, named XYZ. Even if containing $Q\bar{Q}$, $Q = c, b$, in their decay products, almost none of the XYZ mesons can be interpreted as a standard $Q\bar{Q}$ structure, showing production and decay rates in contrast with predictions from potential models. In fig. 1 we show the known [1] XYZ mesons classified according to their decay modes and compared to the standard $c\bar{c}$ levels. There are various phenomenological interpretations for the XYZ mesons. Among the most explored possibilities: i) *hadronic molecules*: bound states of two mesons interacting with each other via pion exchange; ii) *tetraquarks*: compact clusters made up by a diquark, a $[qq]_{\bar{\mathbf{3}}_c}$ state, and an antidiquark, a $[\bar{q}\bar{q}]_{\mathbf{3}_c}$ state; iii) *hybrids*: $q\bar{q}g$ aggregates; iv) *hadrocharmonium*: a heavy quarkonium state $Q\bar{Q}$ embedded inside light hadronic matter. Until now the discovery of the exotic mesons has been fairly accidental, it occurred when studying final states expected for the decays of higher standard $Q\bar{Q}$ states. Here we consider the possibility to reveal the XYZ not directly, but indirectly, taking into account processes in which they behave as intermediate states. In particular we discuss the inclusive production of J/ψ in B decays and consider all the contributions separately following ref. [2].

The data. The BaBar Collaboration [3] measured the decay momentum (p_ψ) distribution of the of the prompt J/ψ's coming from B-mesons decays, fig. 2 (full circles).

The theoretical description [3] in terms of two standard QCD components, reveals an excess of events in the low-p_ψ region (red-dashed line in fig. 2). This discrepancy has provoked a variety of phenomenological conjectures.

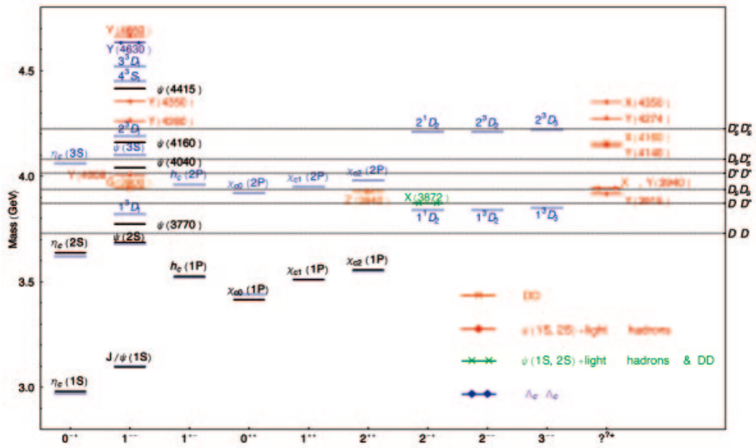

Fig. 1. – (Colour on-line) The spectrum of $c\bar{c}$ states, predictions (solid thick blue lines) and experimental data (solid black lines), together with the known [1] XYZ mesons (colored lines with symbols), which are classified according to their decay modes indicated in the legend.

Besides the standard QCD components, on which we give an update based on the most recent data, we include here the contribution of the process: $B \to \mathcal{K}\mathcal{X} \to \mathcal{K}\ J/\psi +$ light hadrons, where $\mathcal{X}$ indicates one of the XYZ mesons, and $\mathcal{K}$ a generic kaon.

Color singlet. The high momentum side of the spectrum is filled by two-body decays of the kind $B \to \mathcal{K}\ J/\psi$, where the $c\bar{c}$ pair is produced directly in color singlet configuration and thus hadronizes into J/ψ without the emission of any gluon. In ref. [3] only $B \to K\ J/\psi$ and $B \to K^*\ J/\psi$ were included (blue dot-dashed line of fig. 3). Nevertheless a recent analysis by Belle [4] on the $K\pi\pi$ invariant mass spectrum in the decays $B \to J/\psi\ K\pi\pi$ indicates the existence of other two-body modes with heavier kaons, beside confirming the importance of the $K_1(1270)$ one. From Belle measurements we extract the two-body branching ratios $\mathcal{B}(B \to \mathcal{K}J/\psi)$ with

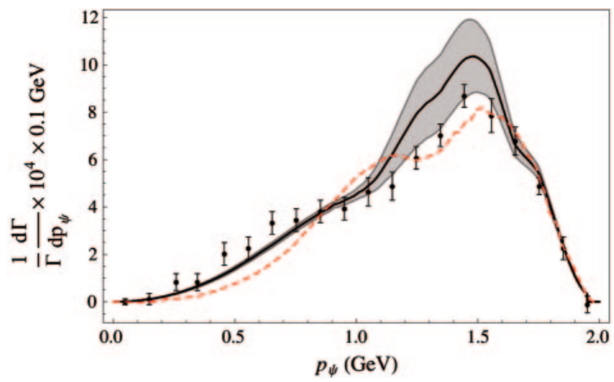

Fig. 2. – (Colour on-line) Comparison between the old theoretical prediction [3] (red-dashed line) and the sum of the three contributions (black-solid line): color singlet, color octet (with $\Lambda_{\rm QCD} = 500\,\text{MeV}$ and $p_F = 500\,\text{MeV}$) and XYZ mesons. Data points from [3].

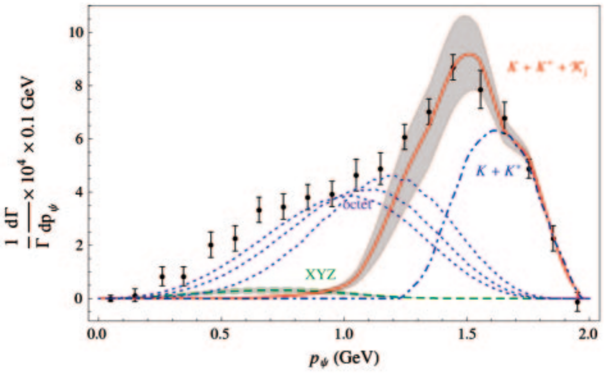

Fig. 3. – (Colour on-line) Color singlet $B \to \mathcal{K} J/\psi$: blue dot-dashed represents $\mathcal{K} = K, K^*$ [3], red-solid includes also the heavier kaons [4]. Color octet: purple-dotted lines for three values of $\Lambda_{\rm QCD} = 300, 500, 800\,\mathrm{MeV}$ and $p_F = 300\,\mathrm{MeV}$ from right to left, respectively. XYZ: green-dashed line.

$\mathcal{K} = K_1(1270), K_1(1400), K^*(1410), K_2^*(1430), K_2(1600), K_2(1770), K_2(1980)$. They are reported in table I of ref. [2] and combined to give the red-solid line of fig. 3.

Color octet. The low momentum region is associated to events where the $c\bar{c}$ pair is produced in color octet configuration, and thus emits soft gluons to fragment into J/ψ. As proposed in ref. [5] the effect of the emitted gluons on the momentum distribution can be modeled using a non-relativistic shape function (with a characteristic energy scale of $m_c v^2 \approx \Lambda_{\rm QCD}$). Moreover the motion of the b quark inside the B meson can be described using the model given in ref. [6] with a characteristic momentum p_F, the Fermi momentum. The shape of the color octet component is ruled by the values of $(\Lambda_{\rm QCD}, p_F)$, but the absolute normalization, which depends on the non-perturbative non-relativistic QCD (NRQCD) matrix elements, needs to be adjusted to data.

XYZ mesons. Some of the XYZ mesons have been observed in B-decays, produced in association with a scalar kaon with known branching ratios (see table II of ref. [2]). Among them $X(3872)$, $Y(3940)$, $Y(4140)$ and $Y(4260)$ decay into J/ψ and light hadrons, and thus do contribute to the p_ψ spectrum. Besides the $B \to K\mathcal{X}$ modes, we decided to include also $B \to \mathcal{K}\mathcal{X}$ ones, where $\mathcal{K}$ are all the heavier kaons allowed by kinematics. To determine the relative branching ratios, which are not measured, we use a simple scaling rule for the couplings deduced from a partial wave analysis. All the XYZ here are considered to be $J = 1$ resonances. The results are represented by the green-dashed line of fig. 3. Even if very small, the contribution from exotic mesons peaks exactly in the region of the discrepancy between theory and experiment, as first observed in ref. [7].

Results. The complete distribution is obtained by summing up the color singlet, color octet and XYZ components. The values of $(\Lambda_{\rm QCD}, p_F)$ and of the absolute normalization of the octet curve are used as free parameters. To best fit data (black-solid curve in fig. 2) we choose the octet component with $\Lambda_{\rm QCD} = 500\,\mathrm{MeV}$ and $p_F = 500\,\mathrm{MeV}$. Both these values are critically on the high sides of the allowed ranges, $\Lambda_{\rm QCD} \in [200, 450]\,\mathrm{MeV}$ and $p_F \in [300, 450]\,\mathrm{MeV}$. Yet the black-solid curve in fig. 2 represents a considerable improvement with respect to the old one (red-dashed). Relying on the validity of the NRQCD approach, our results indicate that the inclusion of new resonances of the XYZ kind feeding the low-p_ψ region would effectively improve the agreement with data.

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